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# Sinistral shear during Acadian deformation in north-central Newfoundland, based on transecting cleavage: Discussion

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Blewett and Pickering (1988) proposed a major sinistral shear in north-central Newfoundland based on cleavage and bedding orientations. They correlate this deformation with the sinistral shear in the British Caledonides reported by Soper (1986) and other workers. We have been working in the Notre Dame Bay area of north-central Newfoundland for a few years and we were surprised by the apparent simplicity of Blewett and Pickering's interpretation, since the area is complexly deformed and there are several generations of folds and cleavage. If Blewett and Pickering do recognize this complexity, they did not account for it in their paper, despite its obvious relevance to their interpretation. Any structural interpretation of the area which fails to consider multiple generations of folds and cleavage cannot be meaningful.

Blewett and Pickering present pole figures of bedding and cleavage, and claim that there is a "mean first penetrative slaty-cleavage trend transecting the regional strike of folded bedding with a 7° clockwise sense". They make a similar claim for previously published data (Horne 1968, Karlstrom *et al.* 1982) and interpret the 'transection angle' as indicating sinistral transcurrent shear. Their suggestions, however, are not even supported by their own data, as we indicate below.

Their poles to bedding and cleavage are similar to what we observe in low strain areas in Notre Dame Bay, and are too scattered to meaningfully define a 7° clockwise transection angle. In fact their data (their fig. 2) can be equally interpreted in terms of anticlockwise transection. More importantly, however, their fig. 3 shows a bedding–cleavage intersection that plunges shallowly to the northeast or southwest, which we find typical of our low strain areas. Obviously in such a situation, whether cleavage strikes clockwise or anticlockwise of bedding depends on the plunge of the intersection lineation, and the relationship will change wherever the lineation passes through the horizontal. Typically on New World Island and in the Bay of Exploits, north-central Newfoundland, the lineation plunges northeast and the relationship is anticlockwise (data from van der Pluijm 1986, Elliott 1988, unpublished work by B. Lafrance and P. F. Williams).

The geometry described above and represented in their figs. 2 and 3 cannot be interpreted in terms of transcurrent ductile shear. If it is assumed that the shear-zone cleavage is approximately parallel to a principal plane of strain (an assumption commonly made in this context: Ramsay 1963, Borradaile 1978, Stringer & Treagus 1980, Treagus & Treagus 1981), then a shallow bedding–cleavage intersection cannot indicate purely transcurrent movement where the movement zones are parallel to the steeply dipping bedding, as they are in Notre Dame Bay. This shallow intersection may indicate a vertical component of movement or may be associated with folds related to the shortening component of a transpressive deformation, rather than being related to the transcurrent component.

In addition to the low strain domains described above, we also recognize many northeasterly trending, high strain domains in Notre Dame Bay. Some are zones of transcurrent movement, and have a very different geometry to that described by Blewett and Pickering. They are zones in which bedding and cleavage are both steeply dipping and in which the two intersecting surfaces define a steep lineation. In these zones, cleavage generally strikes oblique to bedding in an anticlockwise sense, although clockwise 'transection' is also observed.

Underlying the interpretation of Blewett and Pickering is the assumption that folding preceded cleavage formation, resulting in the clockwise overprinting of folded bedding by the cleavage. There is no reason to suppose that folding preceded cleavage formation unless clear *mesoscopic* overprinting of fold hinges by cleavage can be documented. Such overprinting may only be visible in the hinges of mesoscopic folds. If the cleavage is obscured in the fold hinges, as it commonly is on New World Island, the cleavage will appear to overprint or transect the fold (e.g. Williams 1985, fig. 9). Furthermore, it is necessary to establish independently the association of the folds and cleavage to a movement zone before attempting any interpretation of the regional sense of shear. In areas of multiple deformation, the relationship between folds and a cleavage obliquely cutting them can be interpreted equally as an overprinting or a transection, unless both can be shown to have developed more or less synchronously. The sense of shear must also be established independently of the transection criterion, since the relative orientation of fold axes with respect to the cleavage in a transpression situation is dependent on the relative timing of cleavage and fold formation (Soper 1986, Craig 1987).

In summary, we consider that Blewett and Pickering failed to: (1) account for the presence of more than one tectonic foliation in the area; (2) present adequate data to support their conclusions; (3) present mesoscopic evidence of overprinting of fold hinges by a cleavage; (4) establish the association of folds and cleavage with a movement zone; and (5) establish the sense of shear independently of the transection criterion. We therefore conclude that their interpretation of Acadian deformation in north-central Newfoundland is invalid, and their correlation with the British Caledonides is unwarranted.

## Sinistral shear during Acadian deformation in north-central Newfoundland, based on transecting cleavage: Reply

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We welcome the opportunity to reply to the criticisms of our paper by Lafrance, Williams & Elliott. We would address their specific criticisms as follows.

We are surprised that Lafrance *et al.* regard our structural work has having an "apparent simplicity" because the area is "complexly deformed and there are several generations of folds and cleavage". This complexity is addressed in Pickering (1987a, table 3, p. 234). The sole purpose of our short communication was to discuss the earliest regional, penetrative, deformation of the Caradoc and younger succession in north-central Newfoundland, in the context of transecting cleavage. We did not fail to recognize other deformation.

Three principal phases of deformation have been recognized in north-central Newfoundland (Pickering 1987a), with five discrete phases identified by Blewett (unpublished research), and the 'Acadian' ($D_2$) referred to in our paper produced the NE–SW-orientated regional structural fabric, including the main penetrative slaty cleavage. The $D_2$ phase is overprinted by intrusions and is dated as pre-late Silurian (Lafrance & Williams 1988). Folds associated with this deformation are generally tight to isoclinal and essentially upright (although not invariably so).

A locally developed $D_1$ deformation is recorded by NNW–SSE-trending $F_1$ folds with a weak axial planar $S_1$ cleavage, together with SSW-directed $D_1$ thrusting (work in preparation). $D_1$ structures are overprinted by the regional $S_2$ slaty cleavage and locally refolded by $F_2$ folds.

The 'Acadian' structures are cut by locally developed $F_3$ folds with an axial planar $S_3$ crenulation cleavage, kink bands and faults. There is also evidence for reactivation of some of the major fault zones such as the Lukes Arm–Sops Head and Lobster Cove–Chanceport Faults.

With regard to tectonic complexity, the Caledonides of Britain and Ireland are complexly deformed, yet this has not precluded the recognition of transected folds (Murphy 1985, Soper 1986, Soper *et al.* 1987, Woodcock *et al.* 1988). We have merely applied some of the same structural analytical techniques to the Appalachians of Newfoundland, and come up with similar results.

We examined the deformation both within the fault blocks and the fault zones over a broad area in the Badger Bay, Seal Bay, New Bay and Exploits Bay region of north-central Newfoundland. In fault zones with complex histories of reactivation, regional extrapolations and interpretations based on aerially-restricted data from one zone should be treated with extreme caution. Local promontories and re-entrants in the continental margin of Laurentia will have produced anomalous kinematic indicators for the overall shear sense. Hence there is a danger in making plate-scale inferences from limited observations from one geographically-restricted fault zone (albeit a major fault system) in north-central Newfoundland.

The data presented in our paper involved the first regional and penetrative slaty $S_2$ cleavage which we observe to transect the associated fold axes in a clockwise sense. The approach adopted was to study, stereographically, whether these were local anomalies or part of a more regional pattern. The fold axis is defined by the pole of the great circle that is the best fit of the poles to bedding. The slaty cleavage was contoured and the average cleavage plane defined. Our stereonets (cf. Blewett & Pickering 1988, fig. 2) have computer-generated poles and great circles. We are currently evaluating the significance of this methodology statistically. We stressed, however, that the clockwise transection of folds is something that is real and observable in the field, a point apparently missed by Lafrance *et al.* when they claim that we fail to provide mesoscopic evidence for our sinistral shear model.

For an axial planar cleavage, the fold axis will plot as a pitch on this average cleavage plane. Blewett & Pickering (1988 fig. 2) demonstrated that this was not the case. We then noted that Horne (1968) and Karlstrom *et al.* (1982) showed stereonets that reveal a small-angle clockwise transection, although in neither case was any inference drawn from this.

Lafrance *et al.* comment on the periclinal swing of bedding–cleavage intersections (Blewett & Pickering 1988, fig. 3), and state that this is a function of the acute strike between both fabrics. This does not mean, however, that there is a periclinal swing about a similar axis for the fold axis. If this were the case, then the SE plunge would be 180° to the true fold axis. Such a hypothetical fold axis would still pitch off the average slaty cleavage plane to give a clockwise transection.

Lafrance *et al.* describe NE-trending high-strain domains, some of which are transcurrent but they do not say what the age of movement is along these zones. They also discuss the anticlockwise difference in strike between shear zones and the cleavage in terms of 'transection'. We use transection in terms of the angle between the fold axial surface (fold axis as a pitch on this surface) and the cleavage related to that phase of folding.

In multiply deformed terranes, the transection of folds by cleavage may be interpreted as a cross-cutting fabric (Williams 1985, Lafrance & Williams 1988). In the post-Caradoc of central Notre Dame Bay (south and away from the Lukes Arm–Sops Head Fault zone), however, there has been only one major regionally recognizable phase of deformation which resulted in the Acadian folds and it is associated with one main penetrative, regional, slaty cleavage. The other fold phases, although important, are locally developed. Prior to the recognition of the significance of small deviations of cleavage from being axial planar, this cleavage was seen as being axial planar (Helwig 1967, Horne 1969, Nelson 1979, Karlstrom *et al.* 1982, van der Pluijm 1986). We maintain that it is related to the main Acadian folds but it transects the folds in a clockwise sense by less than 10° (Δ).

Lafrance *et al.* claim that we fail to establish a case for early major sinistral shear independent of our transection criteria. This is clearly not the case. Our Short Note focused on the observation and interpretation of transecting cleavage; we referred to Pickering (1987a,b) and Pickering *et al.* (1988) for data and summaries of the possible plate-tectonic evolution of north-central Newfoundland. We refer Lafrance *et al.* to these papers again.

We have examined the outcrop of the major Lukes Arm–Sops Head Fault zone, and find that the kinematic indicators (e.g. Z-folds looking eastward) suggest dextral shear. We do not see this as conflicting evidence against the transecting cleavage that suggests sinistral shear. The Lukes Arm–Sops Head Fault is a major structure correlated with the 'Red Indian Line' (Williams *et al.* 1988). It has a primary 'Z' shaped sigmoidal trend and has been important in controlling the tectonic evolution of central Notre Dame Bay. During the $D_2$ phase of deformation the shape of the Lukes Arm–Sops Head Fault acted as a releasing bend for local dextral shear. This local zone of dextral shearing is not incompatible with overall sinistral transpression on a plate scale during $D_2$ deformation.

Lafrance *et al.* tend to doubt the validity of using transecting cleavage relationships because they subscribe to the view, as expressed by Ramsay & Huber (1983), that slaty cleavage is a result of plane strain with its development tracking the *XY* principal plane; i.e. perpendicular to the shortest axis of the finite strain ellipsoid. Soper (1986) suggests that penetrative slaty cleavage commonly involves pressure solution with or without crenulation, and that deformation rarely conforms to the bulk standard coaxial strain pattern. We see no reason to reject the validity and efficacy of using transecting cleavage as a tool in understanding the nature of transpression in north-central Newfoundland. In this region, buckling appears to have preceded the development of the associated regional penetrative slaty cleavage and, therefore, the conditions are fulfilled to use transecting cleavage to suggest a late Silurian $D_2$ sinistral shear. Since Lafrance *et al.* start from a different premise about the nature of cleavage development, we are not surprised that they cannot reconcile our observations and interpretations with their own.

We believe that we presented adequate evidence for our interpretation of early sinistral shear during compression in north-central Newfoundland. We have not closed our minds to alternative structural interpretations, but we do not accept the reasons of Lafrance, Williams and Elliott for rejecting our observations and interpretations.

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